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EARTHING ELECTRICAL SYSTEMS TO WATER PIPES[1]

By Burton McCollum and O. S. Peters

The protection of persons and property against electrical dangers has in recent years become an important problem. In the beginning of the art of distributing electrical energy to consumers voltages were low, direct current was used, and in the case of each system the points of consumption were confined to a comparatively restricted territory. Then the dangers to persons from electrical circuits were practically negligible, but the dangers to property were not, because insulation and methods of construction were undeveloped. At the present time, however, far different conditions exist. Electrical systems have been enormously extended, and the demand for economical operation of the extended systems has brought about the use of voltages greatly exceeding those used in the beginning. The development of alternating current machinery and methods of transmitting electrical energy over long distances has been chiefly instrumental in bringing about the new conditions. With the increase in the voltages at which electrical systems are operated, dangers to persons and property have multiplied. It is true that improvements in methods of construction and quality of insulation have kept pace with the growth of electrical systems, or vice versa, whichever way one chooses to look at it, but at the same time many dangers arise from electrical circuits which require special means and devices to render them harmless. One of the most important sources of danger is that due to the close proximity between highvoltage and lowvoltage circuits in transformer windings, on pole lines, in manholes, and other places where, for lack of space or for other reasons, it is necessary to place such circuits near each other. The actual danger in this case arises from the entrance of voltage and current from the highvoltage circuit upon the lowvoltage circuit through faults in insulation, contacts between wires and in other ways. The great importance of this source of danger is due to the fact that large numbers of people are continually coming in contact with apparatus and appliances connected to these lowvoltage circuits. It is, therefore, the duty of persons installing such circuits to make them as safe as it is practicable to make them; and it is, moreover, to the best interests of everybody concerned with them that they should be made safe. Much can be accomplished in this respect by connecting these lowvoltage circuits to earth in the proper manner. It is the purpose of this paper to discuss briefly the principal causes of the dangers just mentioned, the desirability of connecting lowvoltage secondary circuits to water pipes to avert these dangers, and also the effect on the pipe systems of such earthing.

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[1] Read at Central States Section Meeting.

DANGERS FROM ELECTRICAL SYSTEMS

The most common forms of lowvoltage circuits are those fed from highvoltage alternating current circuits through stepdown transformers. In this case the danger arises from the entrance of current and voltage from the highvoltage circuit either through leaks in transformer insulation or contacts between wires. Leaks in transformer insulation are caused in most cases by lightning striking the line and puncturing the insulation between windings. Much effort has been expended in developing lightning arresters to take care of these lightning strokes without injury to the transformers, and much has been accomplished, but complete protection is not now obtainable. Contacts between line wires result from storms, electrical accidents to cables and other causes.

As an example, take a transformer connected to a 2200 volt distributing system which transforms energy for lighting a group of dwelling houses by means of a 3-wire 110 to 220 volt circuit. If during a storm a highvoltage line wire breaks and falls on a lowvoltage wire, or any one of the possible accidents occurs which may have a similar result, a condition may arise such as that illustrated in figure 1. That is, one side of the lowvoltage circuit is, in effect, connected by a wire to one side of the highvoltage circuit. If both circuits are insulated from ground at all points, an electrostatic voltmeter, or some other voltmeter which takes but slight current to operate it, will show at V a difference of potential approaching 1100 volts between lowvoltage circuit and ground, the actual voltage indicated varying with a number of factors. It is not likely, however, that either circuit will be thoroughly insulated at all points. There may be faults in the insulation, and if there are the voltmeter may read as high as 2200 volts. This would be the case if the opposite wire of the highvoltage line were down and touching ground somewhere, or were even in contact with a tree.

In either case if the lowvoltage circuit were in any way accidentally grounded, the flow of current to ground might be considerable. In the first case the current flow that might occur would be due to the electrostatic capacity between the highvoltage line and ground, the line acting as one plate of a condenser and the earth as the other. The alternating voltage of the line itself would tend to charge and discharge this condenser through the fault *A* in figure 1 in series with whatever accidental ground happened to be on the lowvoltage circuit. This might be the body of a person in contact with lighting fixtures. The value of this condenser current can be shown

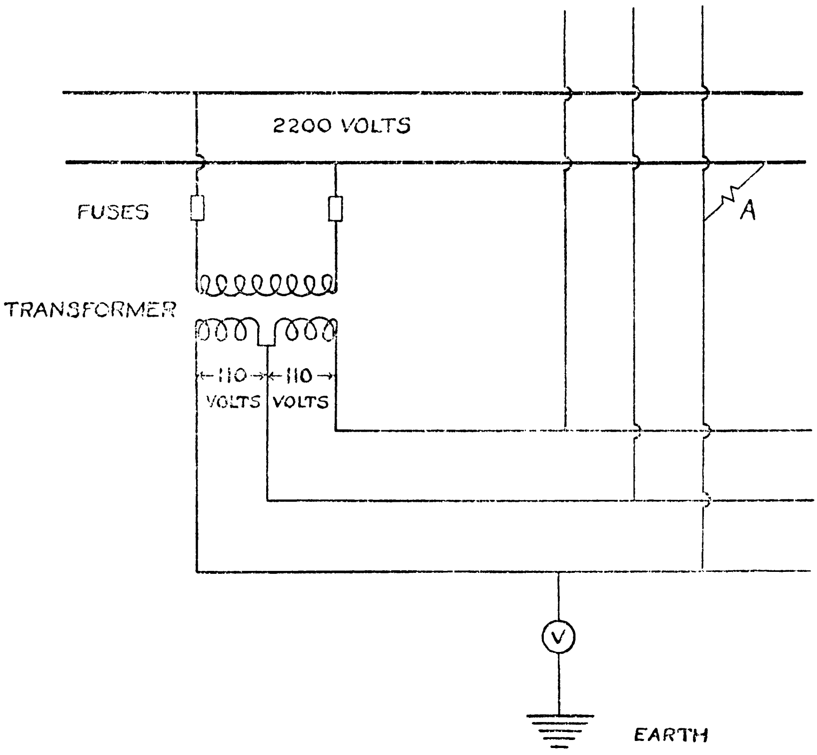

FIG. 1

to be about 10 milliamperes per mile of line. The magnitude depends directly upon the length of the line so it would reach a dangerous value with a length of line of 10 miles. In the second case the current would depend upon the sum of the resistances between lowvoltage circuit and ground and between the opposite wire of the highvoltage circuit and ground. Similar conditions may arise with any lowvoltage circuit if it comes in contact with a highvoltage circuit.

PROTECTION AGAINST THE MAXIMUM DEGREE OF DANGER

It is obvious that when there do exist such high voltages between lowvoltage circuits and ground there is great danger to persons handling lamp sockets and other appliances; moreover, there is an extreme likelihood of fire following a failure of insulation of the lowvoltage circuit because of current flowing from the highvoltage circuit to ground and heating inflammable substances. The frequency with which fires and accidents are reported from this cause is sufficient evidence of its seriousness. The condition described above, however, represents the maximum degree of danger which can arise, and the one which is likely to be met with the most infrequently. There may be a lesser degree of danger; such, for instance, as that which would be brought about by a failure of transformer insulation at some place beyond the end turn of the highvoltage winding. In that case the voltage to ground might be only a small fraction of 2200 volts and the danger proportionately less. But it is necessary to protect against the full voltage because this will frequently be encountered.

It is evident, therefore, that in the case of lowvoltage circuits fed through transformers from highvoltage circuits, or where a lowvoltage circuit of any kind is liable to contact with highvoltage circuits, great precautions are necessary to prevent accidents; furthermore, the best available means and devices must be used. From the dangers just described a great deal of protection can be obtained by connecting the lowvoltage circuit to earth as in figure 2. For the best degree of protection it is necessary that the resistance to flow of current from the lowvoltage circuit through the earth wire *B* and earth connection *E* be very low. That is, a current must easily pass from the lowvoltage circuit into the earth in case of contact with a highvoltage line. If this is the case, and the resistance to flow of current is low enough, a dangerous voltage can not exist between lowvoltage circuit and ground. For example, instead of the voltmeter at *V* in figure 2 reading between 1100 and 2200 volts, as it did under the condition shown in figure 1, it will now read a value which may be found by multiplying the current flow in amperes in wire *B* by the resistance in ohms to flow of current into the earth at *E*. If the resistance at *E* is low, the voltage measured at *V* will be low even though a large current is flowing. The lower this voltage is the better, and for a high degree of safety it should in no case exceed 150 volts. The current which will flow in wire *B* depends upon the current carrying capacity of the protective devices on the line from which the current comes. This may be small or large, and the maximum allow-

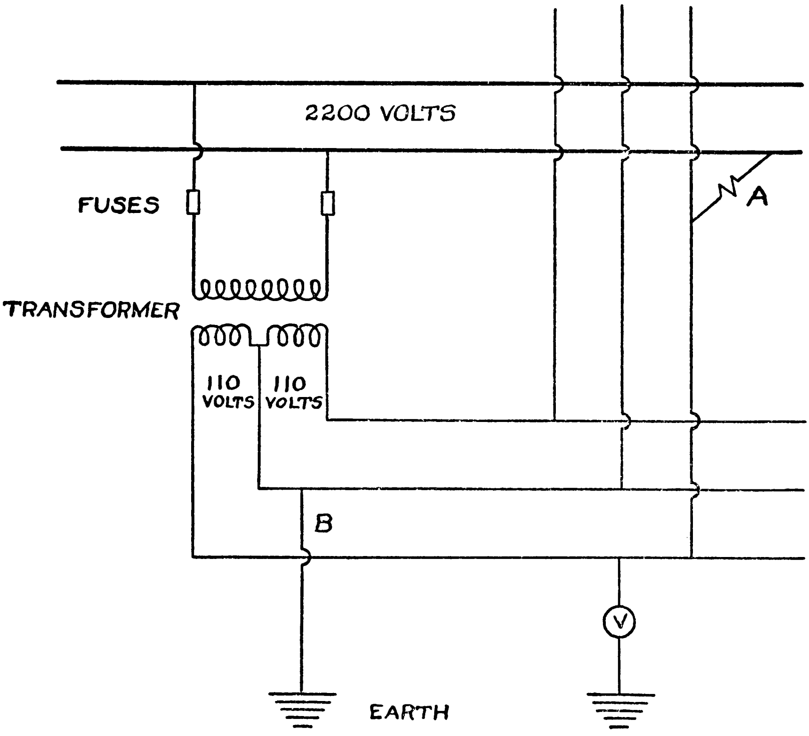

FIG. 2

able resistance in the earth connection at E will depend upon the maximum value of this current. The maximum current which a line will carry permanently is limited by the rated current of the fuses or automatic circuit breakers which protect it from overload. Hence, the maximum allowable resistance in the earth connection can be expressed by the following formula: $R = \frac{150}{I_A}$, where R is the resistance in the earth connection, 150 is the allowable voltage between lowvoltage circuit and ground, and I_A is the current required to operate the fuses or circuit breakers which open the circuit. If this current is 100 amperes, R will be 1.5 ohm; 200 amperes, 0.75 ohm, and so on. One hundred-fifty volts, however, is the maximum allowable voltage rise between lowvoltage circuit and ground. There is a slight possibility of danger from this voltage even, but only under special conditions; so, for practical purposes 150 volts may be considered as a safe limit. Serious accidents to persons from potential differences between lowvoltage circuits and ground of 150 volts or less have been reported only as having happened in very damp locations, or in other places where extraordinarily good contact was made with both lowvoltage circuit and ground.

EARTH CONNECTIONS

The next question is that of obtaining a low value of resistance for the earth connection E. There are several methods by means of which electric circuits can be earthed; namely, by utilizing water pipe systems, driven pipes or buried plates. Buried strips of metal of any desired length may also be used under special conditions, and there are on the market many patented devices for making earth connections. In this list, however, waterpipe systems easily come first in point of desirability. In the first place, on account of their great extent, they offer but little resistance to flow of current away from them into the earth, the resistance of water pipe earth connections being found to be but a fraction of an ohm in most cases. A resistance of 2 ohms would be extraordinarily high. As pointed out later, however, where these low resistances are found the pipe joints for a considerable distance from the earth connection must give as good metallic contact as will ordinarily be found with lead or screw joints. In the second place, water pipes are easily accessible at service pipes or at other places; and, in the third place, it can be shown that with certain precautions all possibility of damage to the pipes, or injury to employees of the water company can be easily avoided. In fact, many dangers considered of importance in the past do not exist where the grounding is properly done.

With regard to driven pipes, buried plates, or strips of metal, and patented earthing devices, table 1 gives the results of measurements on a number of these forms of earth connections made in rather stony clay at the Bureau of Standards. These measurements represent a part of the results of a thorough study of the subject of earth connections for electrical systems which is now being made by the Bureau. The table is practically self explanatory, and shows in general that a low resistance, or a resistance low enough effectively

TABLE 1

Resistance of earth connections. Kind of earth, clay rather stony. Earth connections in place four months and soil fairly moist when measurements were taken.

Type of Earth Connection	*Resistance ohms*
Strips of galvanized iron 1½ inches wide, 20 feet long, in clay 12 inches deep (average of 8)	30
Strip 160 feet long in clay 12 inches deep	5
Strip 60 feet long in trench 12 inches deep with 4 inches of coke in trench, covered with clay	8
Strip 60 feet long in clay 12 inches deep with 1 pound of salt per foot of strip	6
Paragon ground cones 2 feet long, 5 feet deep, in coke (average of 2)	57
Paragon ground cones 1 foot long, 5 feet deep in coke (average of 2)	72
Maxum ground boxes 5 feet deep in clay (average of 3)	52
Brach hydroground, large size, 5 feet deep in clay	61
Brach hydrogrounds, medium size, 5 feet deep in clay (average of 3)	64
Lord disc type hydrogrounds, 5 feet deep in clay (average of 2)	83
Federal Sign System 22 inch cartridge ground plate, 5 feet deep (average of 2)	30
Federal Sign System 10 inch cartridge ground plates, 5 feet deep (average of 2)	59
Plates, 2 by 4 feet, on edge in clay 5 feet deep (average of 3)	33
Plates, 2 by 4 feet, flat in clay 5 feet deep (average of 2)	43
Plate, 2 by 8 feet, flat in clay 4 feet deep	32
Plate, 2 by 8 feet, in coke, 4 feet deep	17
Plate, 2 by 8 feet, in salted earth, 4 feet deep	8
Pipe earths, ¾ inch pipe, 5 feet deep (average of 8)	73
Pipe earths, ¾ inch pipe, 10 feet deep (average of 8)	52

to avert danger of the kind just described, is not easy to obtain by means of any of these devices. In considering the results given in table 1 it should be borne in mind that the resistivity of the soil in which these earth connections were made is considerably higher than the average of that found in practice; although the soil in some places will be of even higher resistance and hence worse for the purpose of making earth connections than that described. It may also be stated as a well known fact that if pipes are driven into the earth at a distance from each other and connected by a wire the combined resistance to flow of current away from the several pipes into the earth will be much less than that of a single pipe. In fact, for pipes driven at 10 feet or more from each other the resistance to flow of current away from them into the earth is roughly inversely as the number. That is, with two pipes driven from 6 to 10 feet from each other the resistance is a little more than half that for a single pipe, with three pipes the resistance is a little more than one-third that for one pipe, with ten pipes one-tenth, and so on. As just stated, this is only roughly approximate and as the number of driven pipes increases the distance between them must also increase in order to maintain even the approximate relationship between number and resistance.

If the resistance of a single driven pipe earth connection in a certain locality were as low as 15 ohms, to obtain a resistance comparable with that of a waterpipe system in the same place would therefore require 50 or 60 pipes driven into the earth at 10 to 20 feet distant from each other and electrically connected together. This is plainly impracticable. It must be granted, of course, that by the use of driven pipes or buried plates a certain degree of protection can be obtained; in the case of small transformers and lines of limited capacity even an ample degree of protection; but as the kilowatt capacity of the lines and transformers increases the resistance required of the earth connection must decrease. The practicable limit of decrease of resistance with driven pipes or buried plates is soon reached, and for the circuits of larger capacity it is imperative that some other means be found. In fact, for all lowvoltage circuits it is highly desirable to have low resistances in the earth connections. The most obvious solution of the problem is to use water pipe systems which, in most cities, cover approximately the same areas covered by the electrical systems. To connect to the water pipe systems is highly advantageous to both the electric company and the consumer.

There are, of course, localities not reached by water systems and in such places it is necessary to resort to driven pipes and other means of making connection to earth. As stated above, where the installations are of small power rating an ample degree of protection can be obtained with driven pipes, and considerable protection even in the case of fairly large installations. In no case should earthing be omitted. If there is sufficient ground space available a number of pipes can be driven to a depth of 8 or 10 feet at a distance of 5 to 10 feet from each other and connected together. If space is lacking, 3 or 4 pipes driven to a depth of 10 feet around a pole will give a resistance which in many cases may be considered sufficiently low. Three pipes driven around a pole and close to it, will be found to have a resistance of approximately 50 per cent of that of one of the pipes.

EFFECT ON WATER PIPES OF USING THEM AS EARTH CONNECTIONS

It has been shown above that it is very desirable to connect low-voltage secondaries to water pipes. It must also be shown, however, that the use of the water pipes for making earth connections is not in any appreciable degree a disadvantage to the pipe owning company. In the past it has been stated that trouble for the company would arise from three sources: (1) Electrolysis by stray currents from the earthed circuits; (2) danger to employees of the water company while working on service or other pipes to which lowvoltage circuits were earthed; and (3) complications from allowing a second public service company the use of the pipes.

The subject of electrolysis in this case may be considered under two heads: (a) electrolysis by alternating current, and (b) electrolysis by direct current.

a. Electrolysis by alternating current. Referring to figure 3, *A* represents an extensive lowvoltage alternating current circuit which is earthed at a number of points to service pipes, these service pipes being all connected to the same water system. It is readily apparent that under normal conditions of operation, or with insulation everywhere in good condition, the opportunity for current flow in the pipes is very slight. With unbalanced load on the system current would flow in the middle wire, setting up differences of potential between the points *e*, *f* and *g*. This would cause current to flow in the pipes, but the voltages between *e*, *f* and *g* being necessarily small, the currents would be small, since there is more or less resistance in the pipes. In no case would the current flow exceed a fraction of the flow in the middle wire.

On the other hand, there can be no interchange of current between circuits *A* and *B*. In order for this to occur, the flow would have to take place from *A* through earth wires *a*, *b* and *c* in parallel, over the water pipe to wire *d* and circuit *B* and back to *A* on the highvoltage line. Two layers of transformer insulation prevent this, so such an interchange of currents is impossible, unless there are faults in the insulation of both transformers. If this should occur fuses 1, 2, 3, or 4, would be likely to go out and isolate the lowvoltage circuit. Or, if the fuses did not go out, the current would be limited to their rated capacity. With a lowvoltage circuit connected to the pipes at a single point or as in *B*, figure 3, there is obviously no opportunity for any but the very slightest flow of current into the pipes over wire *d*, because there is no place for

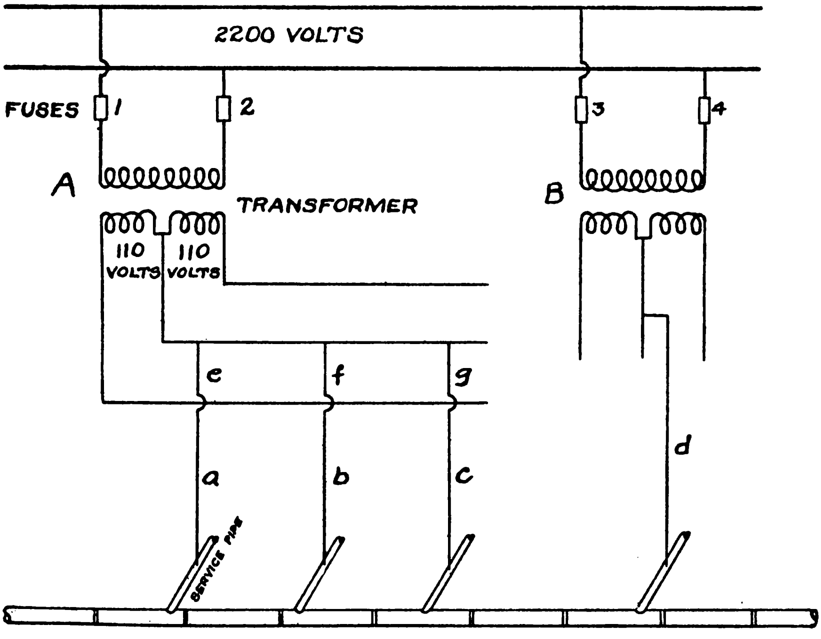

FIG. 3

it to go. The slight current that would flow would be due to electrostatic capacity effects and would hardly be measurable by any ordinary means.

With a condition existing such as that shown in figure 1, however, considerable current might flow for a greater or less time. If the leak should occur to circuit *A*, for example, the current would pass from one side of the highvoltage line through the fault to circuit *A* and to the pipes over earth wires *a*, *b* and *c*, whence it would flow through the earth back to the opposite side of the highvoltage line.

Nevertheless, granted that under normal conditions of operation slight alternating currents may flow, and that in the event of failure of insulation large currents may flow, it has been shown by experiments recently conducted at the Bureau of Standards that the damage by electrolysis from such currents is practically negligible. These experiments, made on both iron and lead, in moist clay, show that with alternating current at commercial frequencies the amount of metal dissolved is but a fraction of 1 per cent of that dissolved by direct current, the quantities of electricity passed being the same. To express the same thing in different words, it may be said that with currents in pipes which are equal in point of quantity of electricity passed, it will take the alternating current hundreds of years to accomplish the damage that would be accomplished by the direct current in a single year. Therefore, from the stray alternating currents which may be found in pipes from earthing lowvoltage alternating current circuits to them no perceptible damage through electrolysis need be feared. The only possibility of damage is that due to heating if the current flow is heavy, but the likelihood of such currents flowing is so small as to be of no importance. Unless the pipes were very small the currents required to damage them would be thousands of amperes, values beyond the range of possibility in any ordinary case.

It has been stated by some that the passage of electric currents over service pipes may heat the water in them which will result in swelling and sticking in the hard rubber parts of water meters. Such cases have, in fact, been reported, that is, where hot water has been the cause of damage to meters. That such heating can be due to electric currents in the pipes, however, is not likely. It is more likely to be due to the backing up of hot water from water boilers into the service pipes caused by overheating and forming steam at pressure sufficient to force the water out of the boiler. Such cases have been investigated and found to be the result of hot water from water heaters. One case, however, has come to the notice of the Bureau in which a street railway track was bonded to a service pipe and in this case the current flow was the cause of considerable heating. With the ordinary lowvoltage alternating current circuit, on the other hand, the possibility of sufficient current flow to cause heating is very remote.

b. Electrolysis by direct current. Electrolysis by direct current may arise, or be increased in two ways. In the first place, where the middle wire of a lowvoltage direct current system is earthed to a pipe system at a number of points, the pipe forms a conductor in parallel with the middle wire, in which case when current flows in the middle wire current will also flow in the pipes. If the resistance of the pipes is comparable in magnitude with that of the middle wire these currents will also be comparable, being shared in inverse proportion to the resistances. This is the same condition as was shown in the previous paragraphs to exist in the case of lowvoltage alternating current circuits, but with the alternating currents the damage is negligible, whereas in the case of the direct currents the damage may be serious, because of the marked corrosive effects of direct current. Earthing direct current systems to water pipes at a number of points is therefore undesirable, and such earthing should be confined to but one point on the system, and that at the power house.

Earthing the middle wire at more than one point is unnecessary, and even when earth connections are made, say, with one to the water system at the power house and others to driven pipes or plates, current flow may be considerable and lead to undesirable results. It is to be recommended, therefore, that the middle wire of 3-wire direct current systems be earthed at the power house only, and all other earth connections to the middle wire omitted. An exception to this can be made in the case of connections to service boxes, because in such cases the resistance to ground will in general be high. There can, however, be no serious objection to earthing to pipe machine frames, conduit, or other metallic objects near or enclosing direct current circuits, and it is desirable to earth them to promote personal safety and safety to property. In this case current would flow only while faults existed in the insulation, and since this flow would be temporary, lasting only until warning could be given of the fault and repairs be made, the resulting damage would be negligible.

In the second place, electrolysis may be increased or transferred from one locality to another, if a lowvoltage circuit of any kind is earthed at different points to two metallically separate pipe systems. For instance, in cities where electric railways with ground return are in operation it may be found that one pipe system is at a considerable difference of potential with respect to another. If a lowvoltage circuit is earthed to both of them current will flow from one pipe system to the other, with danger of overheating the wires and also of increasing electrolysis on the other system. Moreover, if a lowvoltage circuit is earthed at one point to a pipe system that is at a potential difference of several volts against earth, and at another point to the steel work of a building the steel work of the latter takes the potential against ground of the pipe, and danger of electrolysis in the building ensues. On the other hand, if different lowvoltage circuits fed from the same highvoltage distribution circuit are earthed to different pipe systems no current can flow from one pipe system to the other, because, as shown in figure 4, the insulation between transformer windings prevents the flow of current,

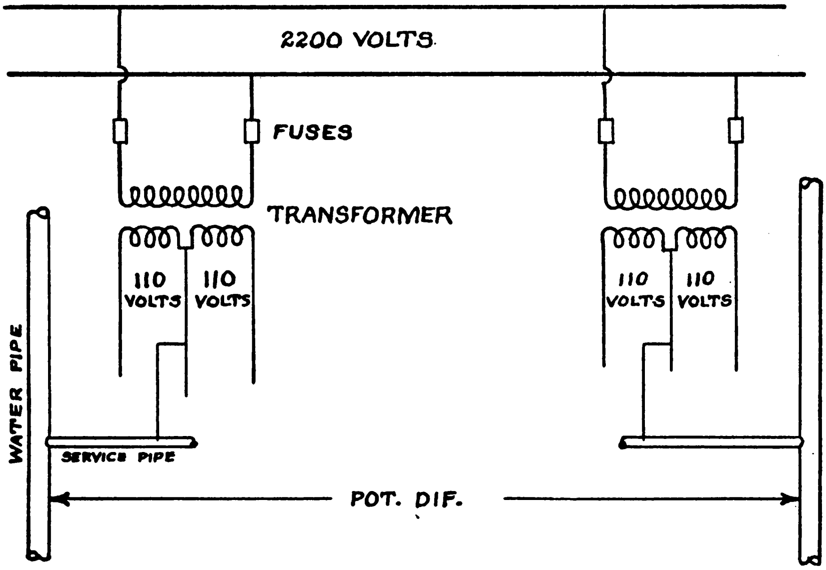

FIG. 4

and current flow would necessarily have to take place over the high-voltage line in order to get from one pipe system to the other. This might occur, of course, if there were faults in the insulation of both transformers, but this is a contingency that can be neglected.

Hence, this general rule can be laid down. In every case where it is necessary and allowable to earth a lowvoltage circuit at more than one point, the earthing should be done to the same pipe system, and in no case should separate pipe systems be used.

INSULATING JOINTS

In connecting a lowvoltage circuit to a pipe system at more than one point, it is important that there be no insulating joints in the pipes that may come between the points of connection. If insulating joints are present, the lowvoltage circuit will act as a shunt to the joint and heavy current flow over the wires may follow if stray currents from street railways are on the pipes. This presents a dangerous condition because of the possibility of fire, and in the case of direct current systems, of increased electrolysis, and should be avoided. Moreover, if there are insulating joints near a point where an earth connection is made to a service pipe, the joints may so restrict the useful pipe surface in contact with the soil as to cause the resistance to current flow from the lowvoltage circuit into the earth in case of an accident to insulation to be so great as seriously to impair the usefulness of the earth connection. For this to be the case it is, of course, necessary to have insulating joints on both sides of the point where the earth connection is made. With an insulating joint on one side of an earth connection and lead or screw joints on the other for several hundred feet the earth connection may be considered good. With insulating joints nearby on both sides, however, as would be the case with a cement joint pipe line, the earth connection would not be very effective. Therefore, in making earth connections using water pipes it is very important to know the character of the joints in the pipe.

PICKING UP STRAY CURRENTS BY LOWVOLTAGE CIRCUITS

If a lowvoltage circuit is earthed to a lead jointed pipe system at several points, and there is current flow in the pipes from electric railway circuits, the current picked up by the lowvoltage circuit is not likely to be of importance. This is due, first, to the fact that lowvoltage circuits are in most cases of limited extent, and hence do not include enough of the pipe line to be subject to a large voltage drop, and, second, to the fact that the resistance per unit length of the middle wire is in most cases large compared with the pipe line. This refers more particularly to alternating current circuits.

DANGER TO EMPLOYEES OF THE WATER SYSTEM

The question of danger to employees of the water company has been many times discussed. In general, it may be stated that danger is likely to arise in only one case and that is illustrated in figure 5.

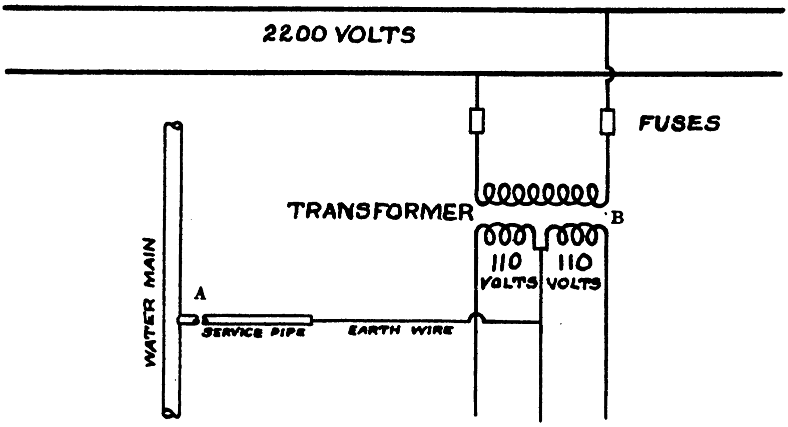

FIG. 5

This shows a lowvoltage circuit earthed at one point to a service pipe, a failure of transformer insulation having occurred at *B*. If the service pipe is disconnected at *A* the person making the disconnection is liable to an electric shock. The severity of the shock depends upon a number of factors which have previously been discussed, and it has been shown that conditions may easily arise under which the severity of the shock would be great enough to cause death. Therefore, with lowvoltage circuits earthed to service pipes at a single point precautions are necessary to prevent such accidents to employees of the water company when working on them. This can be readily provided for by requiring the electric company to disconnect earth wires from service pipes when work is to be done on the pipes and reconnect when the work is finished. This is a reasonable sufficient requirement, and has been in force in several places for years with satisfaction to both parties.

With multiple earth connections to water pipes, however, as shown in figure 3, even the precaution mentioned above is hardly necessary. Unless all of the service pipes to which earth wires have been attached are disconnected there is very little danger. A person may work on one of the service pipes in perfect safety as far as electric shock is concerned if the other service pipes are undisturbed. Moreover, it is an advantage to the consumers using the circuit to have more than one connection to the water pipe, for if one of the wires become disconnected the others still maintain the circuit in a condition of safety. Multiple connection of lowvoltage alternating current circuits to water pipes is therefore to be recommended and encouraged. It should be emphasized again at this point, however, that these multiple connections should be confined to a single water system, for reasons previously set forth in this paper. Moreover, when multiple earth connections to water pipes are made, the resistance of the pipe line between the two farthest removed points of connection should be measured in order to make certain that no insulating joints are present. If there are no insulating joints the resistance will in general be found to be but a small fraction of an ohm. If there are insulating joints it may be as much as an ohm or even several ohms.

MECHANICAL CONSTRUCTION OF WATER PIPE EARTH CONNECTIONS

Where connection is made to a castiron pipe line with bell and spigot joints the most satisfactory method is probably that prescribed by the National Fire Protection Association. This connection is made by drilling a hole in the bell, tapping it, and screwing in a brass plug to which the earth wire is soldered. This joint can be made with a reasonable amount of labor and will be permanent, especially if the surface of the plug and pipe in the immediate vicinity is heavily coated with pitch or something else to prevent corrosion. Where connection is made to service pipes which can be drained of water while work is being done on them the earth wire can be wrapped several times around the pipe and soldered to it. If the service pipe cannot be drained conveniently the next best thing is a clamp to go around the pipe, with a lug to which the earth wire can be soldered. There are a number of amalgams on the market with which the pipe can be treated before putting on the clamp, making a better electrical connection between pipe and clamp than would otherwise be attainable. Many of the clamps sold for this purpose, however, seem of rather flimsy construction. To obtain good results a clamp of sturdy construction is necessary; otherwise it is difficult to get as good a contact with the pipe as is in most cases desirable.

The point at which connections to service pipes are made must be considered. This will in most cases be determined by local conditions. In general, however, it may be stated that this point must be chosen so that there is the least likelihood of the pipe being disconnected between the earth connection and the water main. It is desirable that the earth connection in all cases be placed beyond the point where the service pipe is likely to be disconnected by plumbers altering or repairing piping in buildings. Where the water meter is placed in the basement of a building the earth connection should be made on the street side of the meter if possible. If it is not possible, or if the meter is located in a well or manhole under the sidewalk or street, a jumper, consisting of a wire as large or larger than the ground wire should be placed around the meter, connection being made to the pipe in the same way as for the ground wire.

CONNECTING TO GAS PIPES

Connection directly to gas pipes should in every case be prohibited. The reasons for this are as follows: In the first place many gas mains are laid with insulating joints which are extremely undesirable in a pipe line to which earth connections are to be made. In the second, if a gas pipe in which even a small current is flowing is disconnected a spark may follow and cause an explosion or a fire. In the third place where there are gas pipes there are in nearly all cases water pipes, so connection to the gas pipes is unnecessary.

On the other hand, the connection of lowvoltage alternating current secondaries to water pipes should not only be permitted, but be made compulsory. Such connection has been shown to obviate a hazard that might otherwise arise when lightning or other cause breaks down the insulation of transformer, or wires become crossed. Inasmuch as a considerable advantage to the public results from such earthing, with no appreciable disadvantage to either public service company, there is no good reason why city ordinances or other legislation to require it should be longer delayed. In numerous localities the practice has been tried and found desirable and it should be extended to all localities where highvoltage alternating current distribution systems are in use.

SUMMARY

1. Many of the dangers which arise from electrical circuits may be eliminated by earthing these circuits.
2. Of the means of earthing electrical circuits water pipes are by far the most desirable.
3. There is no danger of electrolysis by such stray alternating currents as may result from earthing lowvoltage alternating current circuits.
4. Direct current circuits should be earthed at but one point, preferably at the station.
5. Where conditions permit two or more ground connections should be made on each secondary system.
6. In the case of any individual lowvoltage circuit in which a number of earth connections to pipes are made the earthing should be confined to one pipe system. Measurements of the resistance of the pipe line between the farthest removed points of connection should be made to make certain there are no insulating joints in that part of the pipe line which may cause the electric circuit to carry heavy stray currents from railways.
7. In making either single or multiple earth connections to water systems, unless it is positively known that there are no insulating joints nearby, the adequacy of the earth connection should be determined by measurement of its resistance. Earth connections should not be made to cement joint lines, or other lines in which there are many joints of high resistance.
8. Connection to pipe lines may be made by screwing a brass plug into the bell in the case of castiron pipes, or by clamps or soldering to service pipes. Soldering is preferable to clamps where it is possible to do it.
9. Earth connections to service pipes should be made at the point where there is the least likelihood of the pipe being disconnected between the connection and the main. If the water meter comes between connection and main a jumper of the same size as the ground wire should be put around it.

10. Earth connections to gas pipes should be prohibited chiefly on account of the chance of explosions or fires, and also because the almost invariable presence of water pipes makes such connections unnecessary.

11. Because of the great advantage to the public and the slight disadvantage, if any, to the public service corporations resulting from earthing to water pipes such earthing of secondary systems should be made compulsory.

DISCUSSION

MR. H. C. HILL: If the companies grounding their telephones use the service pipe in the house, will it affect the telephones in any way?

MR. BURTON McCOLLOM: There probably would be a little disturbance of the telephone system during the time when the high voltage is crossed with the low voltage wires. There then probably would be enough voltage between this ground point and the earth to give a little disturbance, but that is an unusual condition, and it would never be allowed to exist for any length of time, and would be extremely rare.

MR. H. C. HILL: There is a very general practice with telephone companies in some localities to simply solder on to the house service pipes in making their ground.

MR. BURTON McCOLLOM: It is all right to do that. They get a ground for lightning protection, and it is not only a protection to the telephone company but is in reality put in primarily for the protection of the user of the telephone, and because of the fact that it is a measure of public safety, it is something that ought to be encouraged rather than discouraged. The same thing applies to grounding secondaries and transformers to water pipes. That is of no aid to the water company, except that it is a measure of public safety, and consequently something that the water company should encourage.

MR. H. C. HILL: The question was whether that would have any effect on the telephones.

Mr. Burton McCollom: Not if it is properly done.

Mr. O. H. Hutchins: The speaker is not a water man, but an electric light man, but would like to ask a question. Mr. McCollom seemed to be pretty positive in his statement regarding the grounding of neutral to direct current systems, one ground in his estimation being sufficient. Now, not being disposed at all to disagree with Mr. McCollom, but, on the contrary, to agree with him, the question that arose in the speaker's mind was, if that is satisfactory, why is it not just as satisfactory to establish one good ground at the transformer of three wire secondaries, rather than to depend upon a multiplicity of grounds through the various customers' premises? It would seem that the same argument would apply there, that, if it would be satisfactory to a direct current, it would be satisfactory for alternating current.

Mr. Burton McCollom: If you can be sure of getting a good and permanent ground at one point, that is usually sufficient. You need but one permanent ground. The difficulty with having only one ground on each transformer secondary is two-fold. First, there are so many of them in any large distribution system that you cannot give them the maintenance attention that you can give one ground on the D. C. system at the power house. In the second place, the neutral wire of your transformer service generally extends a considerable distance from the transformer serving a number of customers, as a rule, and further, it is a rather small wire, very small compared with the size of conductors we would always have on the D. C. system, and the danger of breakage in the small neutral wire at some point is very much greater than the danger of breaking of the cables usually found in the Edison system, so that there is a much greater probability of the failure of the single ground on the transformer than of a failure of the ground at the power house. That is the principal reason why the speaker would recommend multiple grounds in the case of the transformer secondary, and not recommend it for the D. C. system. It might be added that where the transformer secondary is one of very large power supply, where you have to have large cables, that are not likely to be easily broken there is much less reason for supplying multiple grounds, providing you are sure that the ground you do make is a good and permanent one.

Mr. O. H. Hutchins: The reason that point was raised is not that the speaker is inclined to differ with you, but to bring out this feature, that there may be a hesitancy upon the part of the water companies to allow a ground to their services, due to the fact that the service may be of comparatively small capacity, and it may be at a point where there would be more or less occasion for the water employes to be about, and there might be a hesitancy in granting permission, when granting permission to establish one good ground upon a large water main near a transformer location would accomplish the same results. It seems that a water works man would much prefer extending the privilege of making one good ground than a multiplicity of grounds through all of his varied customers' services.

Mr. Burton McCollom: In reply to that, the speaker would very strongly urge upon the water people that they do not raise any objection whatever to making as many grounds as the lighting company wishes to make on the pipe system. The more frequently the lighting company can ground its system, the less the possibility of hazard, either to the water company employes or to the public. There is one other point that should have been mentioned, that has a bearing on the case, and that is the question of lightning protection. The only effective way to provide for lightning protection is to permit the lightning to discharge to the ground just as quickly as possible. Lightning is liable to strike the service wires between the transformer and the customer's premises, or it may strike right close to the customer's premises. If there is only one ground, and that at the transformer, the lightning discharge, in order to get to the ground, has to go for some distance on the wire to the ground point. It is well known that a lightning discharge has often a wave front, and having a steep wave front, it tends to take the shortest possible path to the ground because of the inductance of any wires along which it might otherwise travel. In some instances a lightning discharge will jump several feet through the air to the ground rather than run 50 yards along a wire to the point where the wire itself was thoroughly grounded because of the inductance of the wire. Now, if you have only one ground at the transformer, and lightning strikes the wire 50 or a 100 yards away from the transformer, the probability that it will jump from the wire to some grounded structure, like a pipe system in the house, is very great and in doing so it may go through a wooden partition and the arc is liable to ignite the wood and set fire to the premises, in addition to possible danger of shock to occupants. This danger is practically removed if you ground the secondary at or very near to each customer's premises. Then the lightning discharge can go directly into that individual ground and will not jump across and possibly give a fire or accident hazard.

Mr. Joe C. Beardsley: There is a question that perhaps might interest some of the members present, and that is the subject of water meters. Almost all water meters used today have hard rubber working parts, and in at least some of them, the clearance on these meters is very small. The majority of meters used today are made of brass. Now, the clearance in the particular meter the speaker has in mind is $\frac{1}{16}$ of an inch, and a very slight degree of heat will expand that hard rubber disc so that it will stick. Is there any possibility of an electrical contact causing heat to expand the disc to that extent? For instance, supposing you grounded a telephone wire on your water service close to the meter, and that became crossed with a high tension wire that would cause considerable heat there. Would that affect the working parts of the meter?

Mr. Burton McCollom: How much clearance did you say there is?

Mr. Joe C. Beardsley: The particular meter in mind is $\frac{1}{16}$ of an inch, that is between the disc and the walls of the disc chamber. That is, it fits quite as close as a piston does in a cylinder.

Mr. Burton McCollom: What is the diameter of the disc?

Mr. Joe C. Beardsley: It depends on the size of the meter. In an ordinary house service meter it is something over three inches, about three inches and a half.

Mr. Burton McCollom: Can answer that only from a rough estimate, not from actual knowledge, but it would seem that it would be practically out of the question that there would be enough expansion due to the heat generated by any current that would flow through the pipes and meter to cause it to stick, because it would not be possible to get enough current through there in any case to generate sufficient heat to raise it above the temperature of boiling water, and that temperature would not be sufficient to expand the hard rubber enough to affect the working parts of the meter.

Mr. Joe C. Beardsley: Still the temperature necessary to expand the rubber need not be over 140 or 150°; that is sufficient to cause the disc to stick.

Mr. Burton McCollom: That may be so. The speaker would not really be able to answer the question definitely at all, except that a pipe with water in it generally has the water running very cool, even if there is considerable current flowing through it, and it is extremely rare that a pipe becomes very warm. What you have in mind is that there is a current that might flow in case of a rather bad short circuit between the high voltage line and the low voltage line.

Mr. Joe C. Beardsley: That is it, with the telephone wire grounded on the service.

Mr. Burton McCollom: On further reflection, there is a possibility that that might be the case. The speaker had in mind a single instance in which a lead service pipe melted off by heavy current flowing in it, and certainly a current of that strength would heat a pipe.

Mr. Joe C. Beardsley: The speaker remembers reading some years ago of a fire that was caused in Boston, in one of the suburbs, by the crossing of a telephone wire that was grounded on a water service, with a high voltage wire; or at least they supposed that that was the cause of the fire, and it would seem that it might also cause damage to meters.

Mr. Burton McCollom: If the ground connection is made on the street side of the service cutoff, probably the heat would not get to the meter to a sufficient extent to cause trouble. Of course, there would be a possibility of some heat conduction along the pipe through the meter, so that one could not positively say it would not happen, even if the connection was made outside of the meter, but in a good many cases the ground is not made far enough out to the street. That is another reason for grounding as near the street as possible; perhaps it is not an important one though.